STATUS
Considering (Retrieving) 01/11/2022
SOURCE
WSILL
BORROWER
FDS
LENDERS
FDA, LOY, BTS, *KSW, COA

TYPE
Copy
REQUEST DATE
01/05/2022
RECEIVE DATE

OCLC #
6981490
NEED BEFORE
02/04/2022

211431899

DUE DATE

BIBLIOGRAPHIC INFORMATION

LOCAL ID Q295 .A88
AUTHOR Zeleny, Milan

TITLE Autopoiesis, a theory of living organization

IMPRINT New York, N.Y. : North Holland, ©1981.

ISBN 9780444003850

SERIES NOTE North-Holland series in general systems research ;, 3

ARTICLE AUTHOR Atlan, Henri

ARTICLE TITLE Hierarchical Self-Organization in Living Systems

FORMAT Book
EDITION
VOLUME
NUMBER
DATE
PAGES Unsure

INTERLIBRARY LOAN INFORMATION

ALERT

VERIFIED WorldCat (6981490) Physical Description: xvii, 314
MAX COST OCLC IFM - 0.00 USD
LEND CHARGES
LEND RESTRICTIONS Please return CDs & DVDs in Box.

BORROWER NOTES Please conditional if COST. Please conditional our request if CITATION INCORRECT. Please give reason for UNFILLED. Thanks!

AFFILIATION CFLC/FLIN/SoLINE/SO6/LVIS/DLLI, Copyright
COPYRIGHT

SHIPPED DATE 01/11/2022
FAX NUMBER 386-822-7199
EMAIL circdept@stetson.edu

ODYSSEY
ARIEL FTP
ARIEL EMAIL

BILL TO Interlibrary Loan
duPont-Ball Library - Stetson University
Unit 8418 - 421 N. Woodland Blvd.
DeLand, FL, US 32723

BILLING NOTES FEIN# 59-0624416

SHIPPING INFORMATION

SHIP VIA lib mail or DLLI
SHIP TO Interlibrary Loan
duPont-Ball Library - Stetson University
Unit 8418 - 421 N. Woodland Blvd.
DeLand, FL, US 32723

RETURN VIA Library Rate
RETURN TO Wichita State University / Ablah Library
Courier--KS734/Room 119
1845 Fairmount Box 68
Wichita, KS, US 67260-0068

Autopoiesis

A Theory of Living Organization

Series Volume 3

Edited by
Milan Zeleny
Columbia University
New York, New York

North Holland
New York • Oxford

Elsevier North Holland, Inc.
52 Vanderbilt Avenue, New York, New York 10017

Sole Distributors outside the USA and Canada:

Elsevier Science Publishers B.V.
P.O. Box 211, 1000 AE Amsterdam, The Netherlands

Library of Congress Cataloging in Publication Data

Main entry under title:

Autopoiesis, a theory of living organization.
(North Holland series in general systems research; 3)

Includes bibliographies and index.
1. System theory—Addresses, essays, lectures. 2. Order (Philosophy)—Addresses, essays, lectures. 3. Evolution—Addresses, essays, lectures, I. Zeleny, Milan, 1942–
Q295.A88 003 80-27038
ISBN 0-444-00385-1

Desk Editor John Haber
Design Edmée Froment
Art Editor Glen Burris
Art rendered by Vantage Art, Inc.
Production Manager Joanne Jay
Compositor Maryland Composition
Printer Haddon Craftsmen

Manufactured in the United States of America

Atlan works with another classical concept of cybernetics—the information theory of Shannon. His concern about complexity and its measurement provides a useful complement to the preceding paper.

The earlier proposition of Von Foerster of order from fluctuations (disorder + noise = order) gains a new significance in Atlan's careful treatment. Two classical limitations of the information theory are being overcome: (1) the creation of information can be explained without contradicting the theorem of the noisy channel, and (2) an approach to the meaning of information is provided by applying the order through noise principle to hierarchical systems.

But the major concern of Atlan is self-organization. He emphasizes the *randomness* of stimuli, fluctuations, or perturbations, as opposed to the programmed ones, as providing the main characteristic of self-organization. Thus he states that the system's organization must be open to such random perturbations (compare with Varela's concept of organizational closure). The reader would probably surmise that Varela could well agree on the complementarity of the two different approaches to self-organization, especially after reading his article in this volume.

The complexity of a system to Atlan is a mechanistic and quantitative attribute, measurable by logarithmic functions. He does distinguish between the complexity and complication and relates them to only partially known natural systems and to fully described artificial systems, respectively. But the complexity is still assumed to be expressible through a unidimensional index, a single number.

As this paper is not related to autopoiesis in any direct way, the reader might also question its appropriateness for this volume. There are several connections. The theory of autopoiesis implies that the notions of coding, programming, and transfer of information become misleading if used as explanatory notions at the cellular level. A good, up-to-date exposure to the theory of information appears to be useful for comparative purposes and as a reference. Atlan provides an interesting discussion of the order from noise principle and its implications for self-organization and evolution: if we know all the internal production mechanisms, self-organization cannot exist! That is, self-organization is an observer-dependent phenomenon, based on perceived randomness or incomplete knowledge and ignorance of the observer. The reader should compare this with the similar conclusions derived by Uribe elsewhere in this volume, although through a different way of reasoning.

Atlan's definition of self-organizing systems takes the role of the observer explicitly into account. Randomness, information, and noise are

viewed as being relative to the observer, or more precisely, to the operations of measurement and control. With Uribe, Atlan could agree that a system can be random (i.e., unknown) with respect to the observer, while being deterministic or ordered (i.e., known) with respect to itself (as if the functioning parts were "known" to the whole).

Atlan's main results seem to be of great value to the current problems with DNA redundancy: self-organization is a unity of continuous disorganization and subsequent reorganization with more complexity and less redundancy. A system should be periodically "recharged" with redundancy in order to be able to evolve.

Henri Atlan was born in Algeria in 1931. He received his M.D. and Ph.D. from the University of Paris Medical School and Faculty of Sciences. His appointments include Professor of Biophysics at the Rouen University Medical School (1966), University of Paris VI Medical School–University Hospital Broussais (1973), and most recently, Professor of Medical Biophysics and Head of the Department of Medical Biophysics at the University Hospital Hadassah in Jerusalem (since 1975). Dr. Atlan was also Research Associate at the NASA Ames Research Center (Moffett Field) in California (1966–1968) and Visiting Professor at the Weizmann Institute of Sciences in Rehovot, Israel (1970–1973). His experimental work in cell biology contributed to the fields of the biology of aging, radiation biology, and cellular cybernetics (membrane-induced regulation of protein synthesis and cell metabolism). His theoretical works have dealt with various approaches to the logic of the integrated biological organization, leading to new developments in information theory and network thermodynamics. Dr. Atlan has published two books (in French) on *Biological Organization* and *Information Theory*. *Address:* The Hebrew University–Hadassah Medical School, Department of Medical Biophysics and Nuclear Medicine, P.O.B. 12 000, 91120 Jerusalem, Israel.

Chapter 12
Hierarchical Self-Organization in Living Systems
Noise and Meaning

Henri Atlan

12.1 Introduction

Shannon's formulas for the functions H and R (respectively, information content and redundancy) have been used extensively to define what order, complexity, and organization are—a need apparently foreseen by von Neumann. He compared the definition and clarification of these concepts to that of energy and entropy in the development of the 19th-century natural sciences.

The order-from-noise principle (von Foerster) and its later development as a principle of information or complexity from noise (Atlan) have helped us to understand in the language of and without contradicting the Shannon theory how information can be created. It has further been used as a basis for a theory of self-organization.

Self-organization has been described as a property of a system in which novelty and changes in organization can be observed. In order for these changes to be real the organization of the system must be open. Otherwise the changes would be contained in the already existing law of organization, which is self-contradictory (cf. Ashby 1962). What makes one call the system self-organizing (although the sources of newness come from elsewhere) is the randomness of the stimuli coming either from the environment or from internal fluctuations in the system (e.g., temperature). In other words, the organization—as a process—of a system implies reactions to stimuli. These stimuli can be either programmed or random. In the latter case the system is called self-organized.

The purpose of this article is to show how this formalism may add something to the understanding of hierarchical self-organizing systems. In addition, the same formalism can give a hint regarding the problem of the meaning of information in such systems.

However, the concepts of complexity, complication, order, and organization are used with different, at times contradictory, implications in the literature. Therefore, before proceeding further, some clarification is needed.

12.2 On Complexity and Related Concepts

12.2.1 Complexity and Complication

It is well known that Shannon's H function represents the missing information that would be needed in order to describe a natural system completely. As such it rightfully measures the system's *complexity* if we realize that complexity is a negative quality: We shall say a system appears *complex* when we do not know how to specify it completely although we know enough about it to recognize it and to call it a system. In this respect, complexity must be distinguished from what we may call *complication*: The latter only expresses a high number of steps necessary to describe or specify or build a system. In this sense, complication should be the attribute of artificial, man-made systems, and its measure, computable from actual blueprints, could be, for example, the minimum number of steps that a Turing machine would need to describe it. In fact, very often such measures are given by means of the computer time needed to achieve some task: The more time, the more complicated the task for the same computing facilities.

12.2.2 Complexity and Coding

As a measure of the information content of a system, H implies the existence of a channel from the system to the observer. Function H is in fact transmitted information in this channel, or the information content of the message output in this channel (Gatlin 1966; Atlan 1968). As information transmitted from the system to the observer, it is indeed transmitted information in the Shannon sense: The coding or decoding of the meaning of the messages at the input and output is taken for granted but is not taken into account.[1]

The observer of the natural system receives the output of a channel without knowing the code that would allow understanding of the messages received and their translation into a specific and explicit description of the system. This imperfect observation at least allows measurements by the observer of the need to know the system completely; it is this meas-

[1] As is well known, Shannon theory is limited to Weaver's level A (transmission of signals within the channel) at the exclusion of levels B and C, which imply the emitter and receiver operations of coding and decoding and have to do with the meaning and efficiency of the message.

urement that is transmitted in the channel to the observer by means of the only possible observations of the system; that is, the probability distribution of the constitutive parts. At the same time, it is this same measurement that allows estimation by the observer of the complexity of this system, whose code (the internal order) is unknown because it is not understood.

12.2.3 Complexity and Levels of Organization

An important consequence, often considered an additional flaw of the classical concept of information content, is that the observation level, although critical, is seemingly left to the arbitrary choice of the observer. The estimates for H can be very different and depend upon the choice of the constitutive elements: elementary particles, atoms, molecules, macromolecules, organelles, cells, organs, organisms, production and consumption units, societies, and so on.

As will be considered further in Section 12.4, the meaning (for the system itself) of the information (that the observer is lacking) is to be found at the articulations between these different observation levels. For example, if the observer chooses to describe a system in terms of its constitutive atoms, information is available concerning only the different kinds of atoms to be found in a statistically homogeneous ensemble of identical systems and their probability (or frequency) distribution, whereas H will measure the missing information necessary to specify the system. Obviously this deficient information is very large compared to the case of the same system described in terms of molecules: In that case we would already make use of additional information that we have, or assume we have, on how the atoms are associated to build molecules, and so much complexity then disappears.

Another, and very spectacular, example is that of the information content or complexity of a living organism, which is considerably reduced when we assume that the organism is completely determined by the informational structure of its genome. The organism's complexity is then reduced to that of its genome, that is, of its constitutive DNA (Dancoff and Quastler 1953).[2] The building of the cell proteins from their constitutive atoms and monomers is no longer considered as a priori undetermined (uncertain) once we know the genome and the mechanisms by which it determines the protein structure. The knowledge of these mechanisms reduces our missing information, that is, the apparent complexity

[2] This widespread idea should be accepted as a working hypothesis or a metaphor and not taken literally, since DNA as a genetic "program" needs the products of its reading and execution (RNA and regulatory proteins) to be read and executed. In living cells, the "program," if any, seems to be identified with the whole cell. The DNA looks rather like the memory where parts of this program are stored.

of the cell system, showing the constraints between constitutive elements. In other words, this reduction is an application of the well-known opposition between H and R: The information and redundancy functions are related by $H = H_{max}(1 - R)$. H measures the complexity because it is the information that we lack; R measures the simplification because it is information that we have, at least in part, about the internal constraints, in the form of the conditional probabilities.

From this point of view a very complicated artificial system—one whose complication would be measured by a large number of instructions to a Turing machine—may have its complexity reduced to zero and redundancy maximum (= 1). In effect we may choose to describe such a system by a function H with only one constitutive element, namely, the whole system already described in a deterministic way by its known blueprint. Our a priori deterministic knowledge of this blueprint allows us to choose the whole system as an elementary constitutive part, just as a priori knowledge of the association of atoms in molecules allows us to consider the molecules as elementary parts instead of the atoms. Again we meet here the basic difference, often forgotten, between well-known artificial complicated systems and natural complex systems.

12.2.4 Measures of Complexity

The feeling of complexity can come first from the large number of constitutive elements. It is measured by their "variety" in the sense of Ashby or $H = \log_2 N$ and does not take into account any repartition of the different elements. An approach to (the imperfect knowledge of) such a repartition is given by the element's probability distribution and leads to a different, lower value of H; this is coherent since the probability distribution already represents some additional knowledge and therefore reduces the complexity. Thus, we can recognize three kinds of complexity, according to the three different expressions of function H. The first, which is trivial (and maximum), is the variety of elements given by $H = \log_2 N$; the second has to do with disorder or statistical homogeneity and is given by

$$H = -\sum_i p(i) \log_2 p(i).$$

Finally, as seen in the previous section, the third is a measure of the lack of knowledge concerning internal constraints (or redundancy) of the system and is given by $H = H_{max}(1 - R)$.

12.2.5 Complexity and Disorder

A system appears to be *ordered* to a given observer if the latter can see some internal articulation and can understand or guess the code that governs the arrangement of the elements. An ordered complexity is no longer

complex, but it may be complicated. The relationship between complexity and disorder appears clearly when we realize that it is a statistically homogeneous structure that is most complex for somebody who wants to reproduce it exactly, distinguishing between molecules having different locations. In fact, maximum disorder (or entropy) looks like maximum homogeneity to the observer, who is unable to distinguish between elements. For the observer, the actual microscopic state cannot be determined since it cannot be distinguished from other states.

Thus, while a state of maximum thermodynamic disorder is seen as maximum macroscopic homogeneity, it is in fact a maximum heterogeneity at a level where we cannot observe it, that of its individual constitutive particles. Thus maximum disorder or homogeneity is a state of maximum microscopic complexity, a state in which we measure maximum missing information.

12.2.6 Order and Redundancy

Known internal constraints within the system can be measured by the redundancy function, which reduces H. Since the latter is a measure of the system complexity and disorder, the former is a measure of simplicity and order. Thus, within the framework of this theory, what we call order appears to be in fact redundant or repetitive order. It need not be physically repetitive in the simple sense of one element repeated many times. But it is redundant in the sense of deductively repetitive: knowing one element gives some information on the others, and this is the source of the appearance of order. & knowability / predictability

12.3 Order-from-Noise and Complexity-from-Noise Principles

12.3.1 Beneficial Effects of Noise

Weaver had already noticed that the effect of noise on signals in a channel increase the message information content at the output, since its uncertainty has increased. This looked to him a paradoxical "beneficial effect" of noise that could not be accepted within the framework of a communication theory, where the goal is to transmit information with as few errors as possible.

However, the situation is different when one is interested not in the output of a given communication channel, but in the information content of a system containing this communication channel as a constitutive part. It is then easy to show that Weaver's first intuition was right and that it can be the basis for a solution of the creation-of-information problem within the framework of Shannon theory (Atlan 1968). In addition, we shall show that it helps somehow to clarify the profound unity of Weaver's three levels of information starting from the narrow definition limited to

level A. This unity was postulated by Weaver immediately after he distinguished among them.

12.3.2 The von Foerster Magnet Model

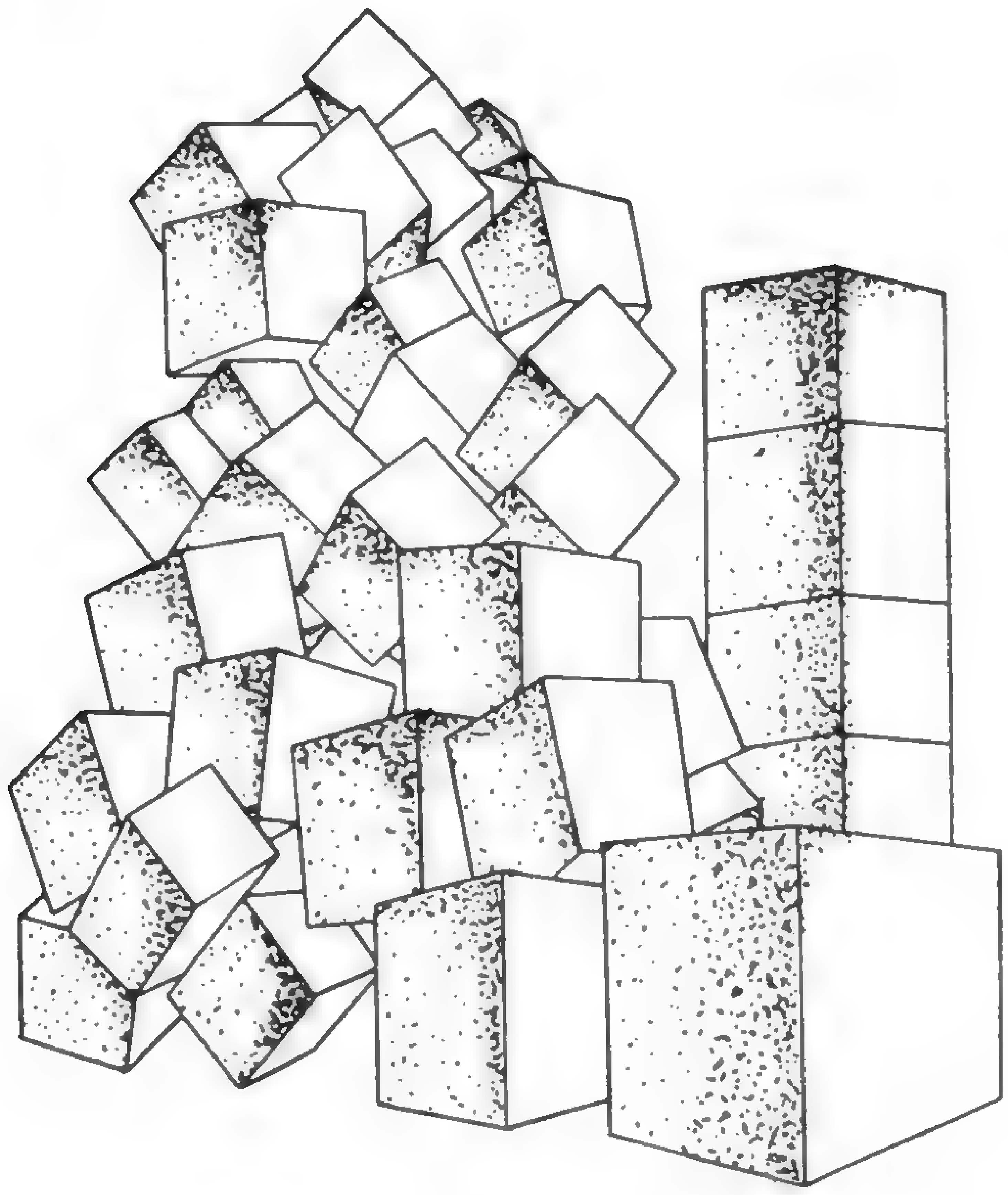
More generally, von Foerster (1960) related the properties of adaptation and evolution to the capability not only to resist but also to utilize the effects of noise and he coined the name "order-from-noise principle." He gave a qualitative example in the form of his famous box of magnetized cubes randomly shaken (Figure 1). However, the quantitative treatment was limited to a simple case in which the ordered structures that appear as a result of the shaking were assumed to be pairs of cubes. According to this treatment his order from noise appears clearly as a repetitive order, or redundancy from noise. On the other hand his qualitative example, where the produced structures are not known—and cannot be known in advance—appears to be a nonrepetitive order, that is, variety or complexity from noise.[3]

More precisely, the whole reasoning in the von Foerster qualitative model is based on the assumption that we do not know that the cubes are magnetized and cannot forsee the structures produced. This is why the system looks to us "self-organizing," it is for this reason that the organized structures that appear as a consequence of the random shaking look to us more complex than the initial random mass. On the other hand, the increase in redundancy calculated for the case that these structures are pairs of magnets is based on our specific knowledge about the structures that appear (namely, that these are pairs). Therefore the assumption is equivalent to knowledge of the internal mechanism (the magnetization) by which the structures are produced, the opposite of the assumption in the qualitative case. It is therefore obvious that it is the complexity that diminishes, as in the example of an organism determined by its genome (Section 12.2.3); indeed, what increases is the repetitive order, as in a crystal formation. The noise allows the constraints potentially contained in the attraction forces to be realized, so that the constructed system will correspond exactly to our a priori knowledge regarding the mechanisms by which it comes about.

---

[3] Now the situation is different from that discussed in Section 12.2.5. Here the absence of structure (or "disorder") of the initial random state of the magnets is seen not as a state of maximum complexity, but as a random mass in which we do not assume any constraint. The apparent disorder or homogeneity appears to represent maximum complexity only if we have some reason to consider it not random but rather the result of some (yet unknown) constraints. Only this assumption can justify the hypothesis mentioned in Section 12.2.5 that the system must be described in terms of its microscopic state. This shows that our intuitive idea of order and disorder is not clear, but based on implicit assumptions regarding both our actual and potential knowledge of the system.

(a)



(b)

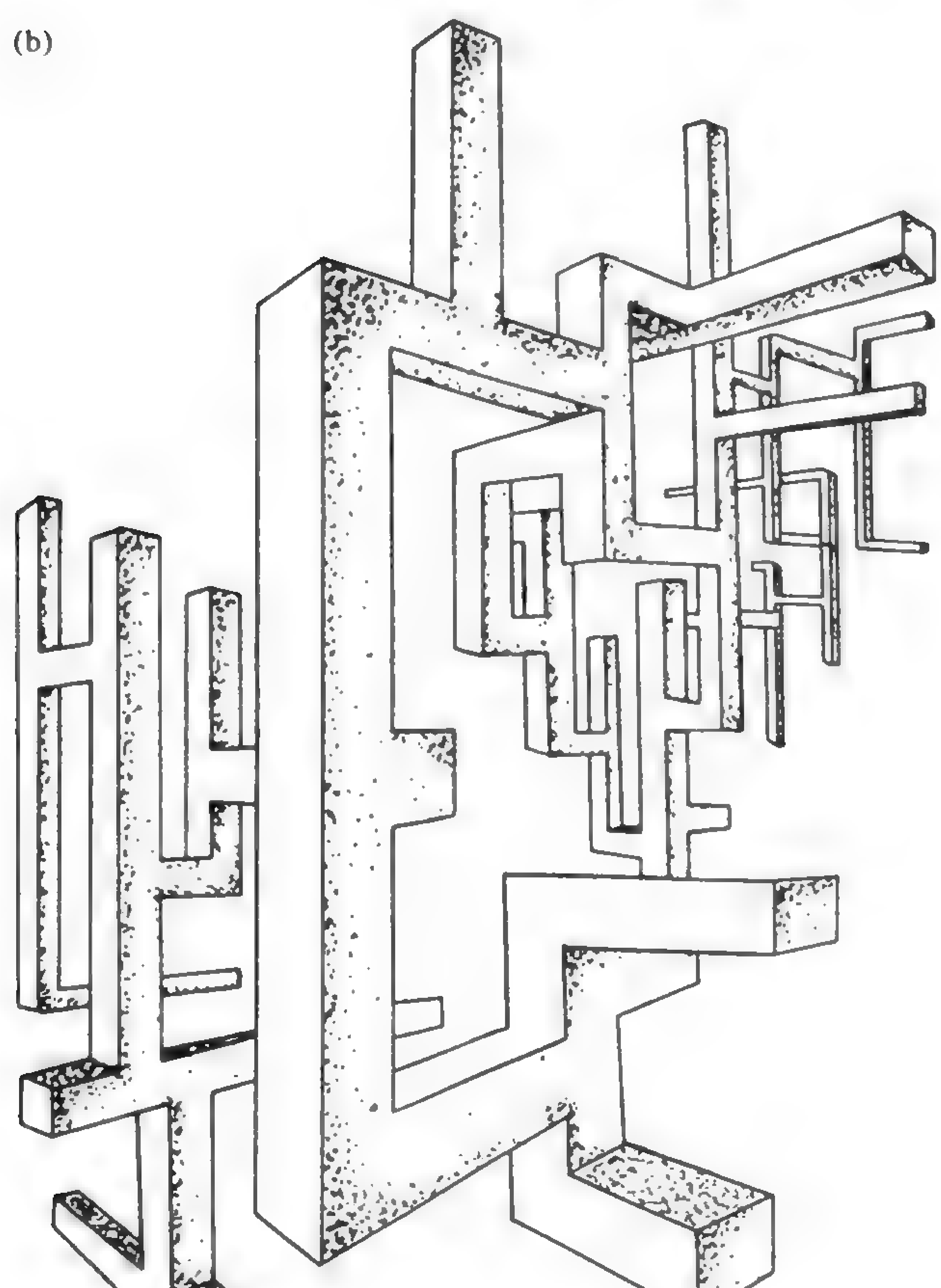


Figure 1. (a) Magnetized cubes (three faces in one direction, three in the other) in a box before shaking. (b) The same cubes during random shaking of the box form geometrical figures subject to change, thus giving the impression of self-organization to an observer who opens the box from time to time.

The great interest of the qualitative von Foerster magnet model, however, lies in the assumption that the observer does not know these mechanisms. This feature makes them a model for systems that look (to us) self-organizing, while it implies at the same time that in the absolute sense (i.e., if we were to know everything about such systems), self-organizing systems cannot exist. Only under this assumption do the structures appear to us more complex than the initial structureless mass, so that our missing information—that is to say, the function *H*—is larger. More precisely, again under this assumption of ignorance of the internal initial constraints (initial magnetization), geometric structures appear more complex than the initial structureless state in the following way. Let us decompose the space occupied by the system into pieces, that is, small elementary volumes to which a probability of being occupied by a magnetized cube can be assigned. The perception of the random mass as unorganized implies that each volume can be replaced by another with corresponding probability of being occupied without producing a sensible change in the global form, which is still perceived as random and structureless. This means that the number of different elements that we would need to specify in order to reconstruct a statistically similar mass (i.e., the number of different volumes with their probability of being occupied) is very small, since important changes in these probabilities for most elements would not affect our perception of the mass as random and structureless. On the other hand, a geometric form (which has appeared seemingly by itself) implies that every cube has a well-defined location in space, which means that volumes and their probability of being occupied by a cube cannot replace one another. In that case the number as elements to be specified is thus much larger, which amounts to a larger value of *H*.

While studying the beneficial effects of low doses of noise-producing factors (ionizing radiation, heat, time of aging) on living systems (1968), we tried several time to give this principle mathematical expression (1972, 1974, 1975). At that time, the necessary distinction between these opposite kinds of order was not so clear. We used the same von Foerster expression of order from noise, while we expressed it as an increase of the *H* function, that is, an information- or complexity-from-noise principle.[4]

[4] In light of the above developments clarifying the identity of complexity and disorder, this amounts to disorder from noise, which seems quite trivial. In fact, the interest of this operation lies in that this complexity or disorder is measured by the *H* function for a natural, not a well-known system. In other words, as already mentioned, the intuitive notion of order or disorder is relative to the knowledge and understanding of the observer.

12.3.3 Complexity from Noise and the Bourgeois Graphs

The transmitted information $T(x;y)$ in a channel is given by

$$T(x;y) = H(y) - H(y/x),$$

where (1)

$$H(y/x) = -\sum_{i,j} p(i)p(j/i)\log_2 p(j/i).^5$$

The function $H(y/x)$, called the *ambiguity*, is an increasing function of the noise in the channel. It measures the independence of y with respect to x and is therefore a loss in the transmitted information. We call it a *destructive ambiguity*.

However, if one is interested in the total information content of x and y, this same function bears a plus sign, as in

$$H(x,y) = H(x) + H(y/x). \tag{2}$$

Here, the independence of y with respect to x measures the decreased redundancy or the increased information content of a system containing x and y. We call it *autonomy producing ambiguity*. Therefore, the sign of this function depends upon the position of the observer: negative when he sits at the output of the x-to-y channel, positive when he sits at the output of a channel from a system that contains x and y as constitutive parts. Thus, we can see how apparently paradoxical positive effects of noise on the information content of a system can be formulated.

These two possible measures of the ambiguity (Atlan 1968) appear most clearly in the graphic representations conceived by M. Bourgeois and shown in Figure 2a. This diagram assumes conservation of that which is flowing, namely, uncertainty. Thus, by specifying that the algebraic sum is zero at each node, one immediately obtains all of the well-known Shannon equations.

We can see that at node C [for channel $(x;y)$] we obtain the transmitted information

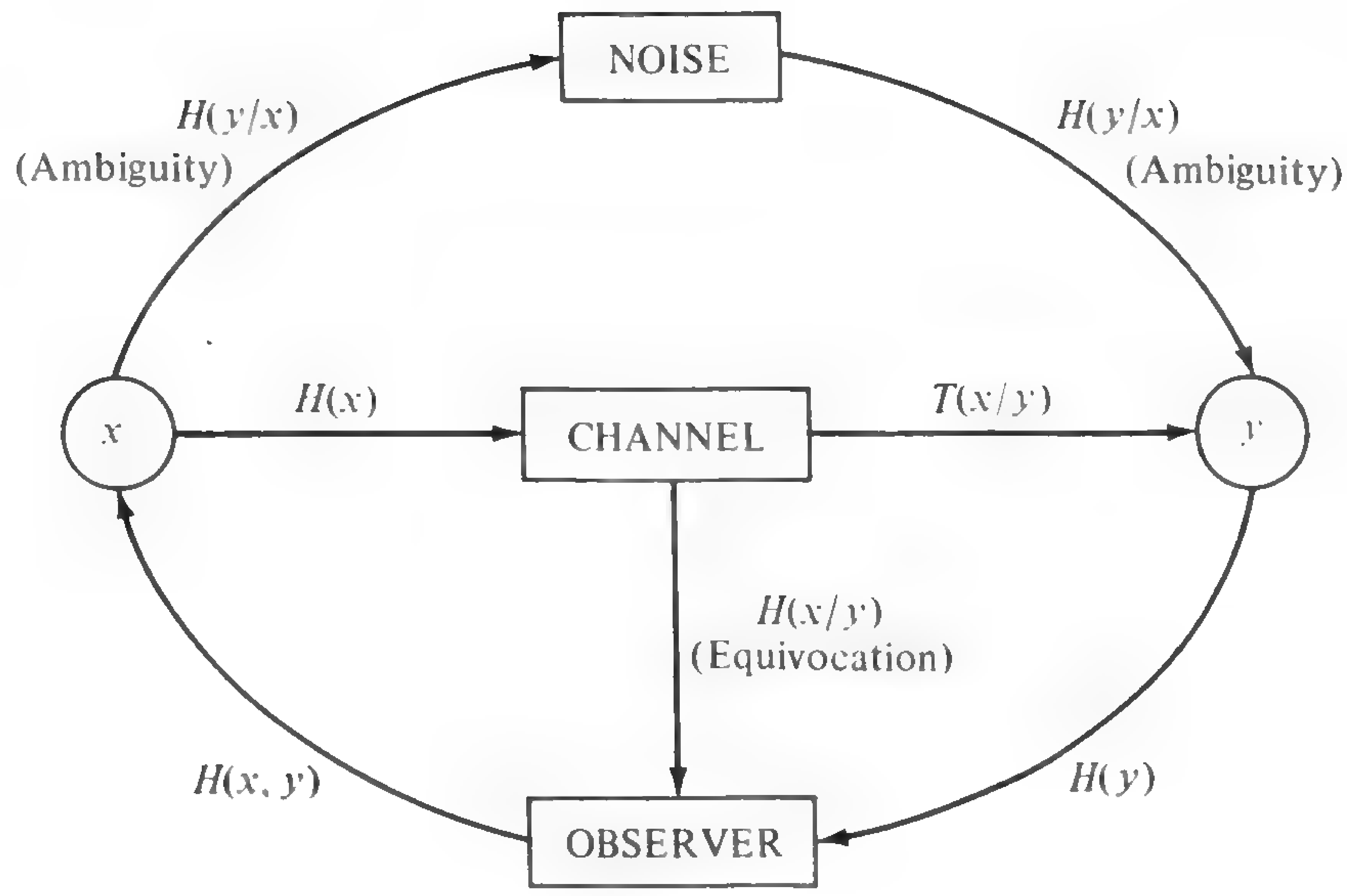
$$T(x;y) = H(x) - H(x/y) \tag{1a}$$

in the channel. Similarly, at node y we get

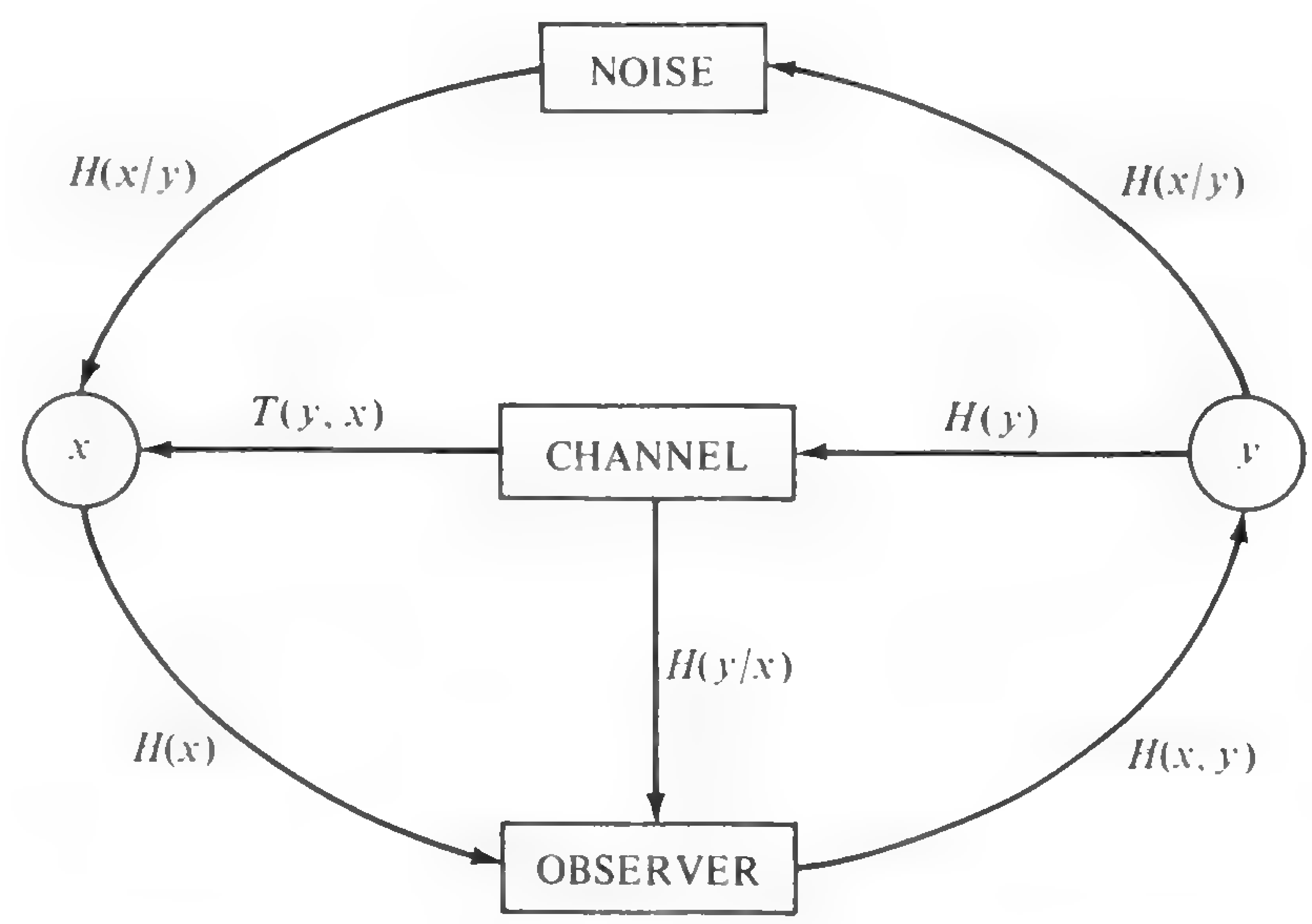
$$T(x;y) = H(y) - H(y/x). \tag{1b}$$

On the other hand, at node O (for observer of the whole channel, i.e.,

[5] The $p(i)$s are the probabilities of the x_i in the input message x. The $p(j/i)$s are the conditional probabilities of having the symbol y_j in the output message y at the place corresponding to x_i in the input.



(a)



(b)

Figure 2. The Bourgeois graphic representation of the two measures of ambiguity (a) assuming conservation of uncertainty and (b) after interchange of input and output.

of x and y) we obtain

$$H(x,y) = H(y) + H(x/y), \tag{2a}$$

and similarly at the node x

$$H(x,y) = H(x) + H(y/x). \tag{2b}$$

If we interchange the variables by setting y as the input and x as the output, the graph is seen to have the same symmetry as the function T (see Figure 2b).

Apart from its value in clarifying these different kinds of ambiguity, the great advantage of the Bourgeois graphic representation is to underline the implicit role and position of the observer in the definition of the Shannon functions. The observer is defined by its knowledge of the plain and conditional probabilities that make up these functions. Thus the existence of a communication channel, with a flow of information in it, implies another flow of information toward the observer. Moreover, the feedback from the observer to the source x, necessary to close the graph and to provide the correct equations, means that the quantity conserved is the total uncertainty $H(x,y)$, which divides into various parts after reaching the source. Thus the real source of uncertainty, which feeds the source of the channel, is none other than the observer. This is another way of noting that the definitions of the information functions depend upon the operation of observing and the level of observation.

This kind of graph can be extended to communication networks with more than two vertices as in the work of W. J. McGill (1954).

12.4 Hierarchical Self-Organization

12.4.1 Complexity from Noise and Levels of Organization

The complexity-from-noise principle has been used as the basis for a theory of (self-) organization (see the Appendix). As such, it may prove to be useful in biology (Nagl) and the social (Morin) and psychological sciences (Ganguilhem, Serres). Our previous observation regarding the two different kinds of ambiguities is based on an analysis of differences in the position of the observer (see Section 12.3).

However, this distinction has a more profound meaning related to a hierarchical organization (Atlan 1975) with different levels of integration of the kind observed in living organisms (molecular, supramolecular, cellular, organ, and physiological systems).

The question of hierarchical organization is a very complex one and not yet solved from a logical and mathematical point of view. When we describe a dynamic system by means of a set of differential equations, the boundary conditions are in general imposed from a different, higher level of integration: For example, the cell, as a set of molecular species that undergo chemical transformations and transports of various kinds, may be described by such a dynamic system. Its boundary conditions will be defined by a state of the cell imposed by the supracellular organization constraints—either the in vitro cell culture conditions or the in vivo constraints of the organ.

Thus it is easy to understand, from a mathematical point of view, how a higher level of organization can determine the structure and behavior of the lower. However, the opposite is much more difficult to formulate,

since it would imply a dynamic system, the boundary conditions of which should be determined by the differential equations themselves. A relatively close analogy to this situation may be found in the analysis of a vibrating sphere, in which the boundary conditions of a piece of the sphere are determined by the state of the adjacent piece and vice versa. Although this situation seems unusual and difficult to formalize from a classical mathematical point of view making use of system dynamics, it is the basis of the day-to-day physicochemical approach to biology, in which the functioning and structure of the organized system is assumed to be determined by the properties of its parts.

Now, we can see that the complexity-from-noise principle can contribute to an understanding of the logic of such hierarchical systems when we realize that the differences in the position of the observer mentioned above can also be viewed as differences in the level of organization of the system itself. In effect, when we consider a communication channel within a system, the output can be viewed as the functioning of the system itself (or at least part of it), inasmuch as the transmission of information in this channel will affect the system's structure and behavior. On the other hand, the global point of view of an observer standing at the output of the implicit channel from the system to the observer can be viewed as that pertinent to the higher level of organization for which the whole system acts as a subsystem, that is, as a constitutive part. Thus the observer for which the ambiguity bears a plus sign is not merely a logical postulate, but also the description of the effects of a lower level of organization on a higher one. As an example, noise in the communication channel between DNA and proteins in a cell has a negative effect when it is felt by the cell itself, in the form of false proteins with nonproper enzymatic properties different from those required by the present state of the cell metabolism. However, these false proteins may have new properties that would make them suitable for new adaptive reactions to a new environment. From the point of view of the organ or physiological apparatus, this same noise has the effects of creating variety and heterogeneity among cells, which allows them more adaptability. Therefore, up to a certain point, and providing the redundancy of the cell is large enough so that these false proteins are not going to impair the cell function, the same effects of the noise on the channel within the cell that are viewed as detrimental by the cell itself can be viewed as beneficial by the organ. Thus the change in the sign of the ambiguity may be understood as a consequence of the change in the level of the observation, which is itself related to a change in the level of a hierarchical organization.

The graphic representation of Bourgeois can help visualize this point. The simplified system of a nonspecific source x and a channel $(y_1;y_2)$ (Figure 3), dealt with in our previous work (1968), is represented in the graph of Figure 4.

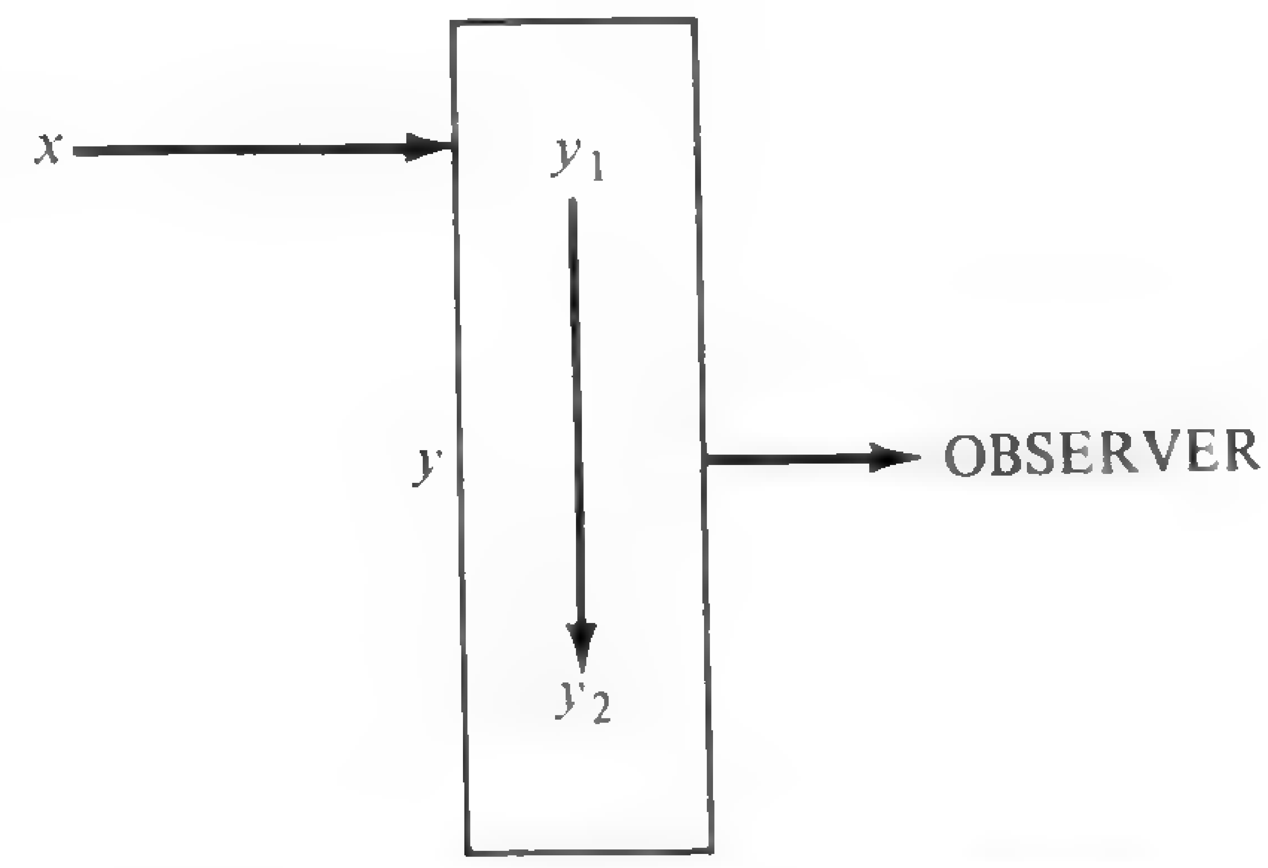


Figure 3. A simplified system consisting of a nonspecific source x and a channel $(y_1; y_2)$.

Our previous equation for the information content of this system

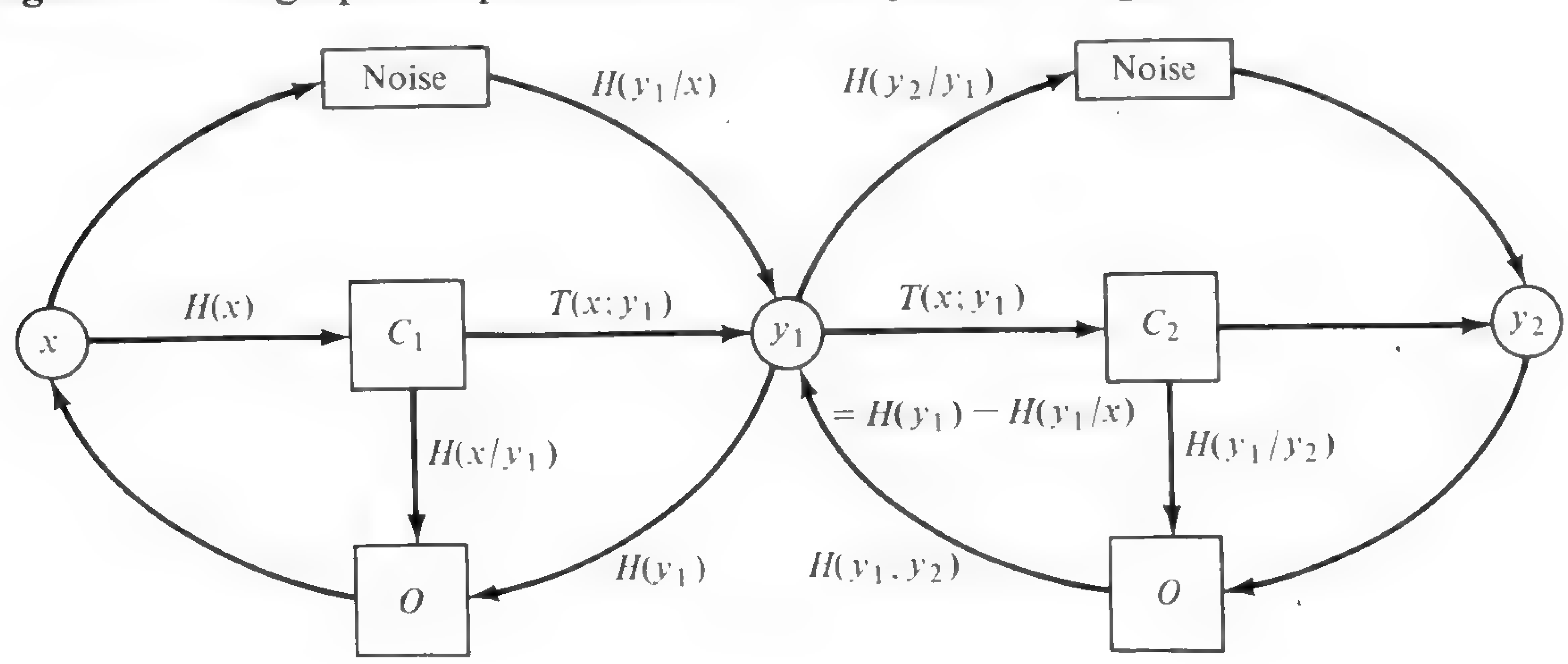
$$H(S) = H(y_1) - H(y_1/x) + H(y_2/y_1) \tag{3}$$

is now obtained by summing up the flows at the node y_1, where we have

$$\begin{aligned} H(y_1,y_2) &= T(x;y_1) + H(y_2/y_1) \\ &= H(S). \end{aligned} \tag{4}$$

In other words, what was called $H(S)$ is nothing else than $H(y_1\ y_2)$ under the condition that the input $H(y_1)$ in $(y_1;y_2)$ is replaced by $T(x;y)$. This amounts to considering the input in the channel $(y_1;y_2)$ as the transmitted information in the previous channel $(x;y_1)$, that is to say, to take into account the ambiguity $H(y_1/x)$ due to the noise in this channel. Thus, because of the asymmetric role of x as a nonspecified source, the communication among x, y_1, and y_2 must not be seen as a communication network with three vertices. Rather, it is a link between two separate channels. These channels remain closed on themselves because they represent two separate hierarchical levels, which means also two different

Figure 4. The graphic representation of the system of Figure 3.



levels of observation. This is why the link between them does not cancel their individual closure by means of two separate "observers." This link takes place by means of a noiseless transmission of what was transmitted at the output of the first to the input of the second. (A noisy transmission between one level and the other would imply an additional decomposition of y_1 from C_1 and C_2 through an additional noisy channel between them.)

It is worth noting that Eq. (3) relies on the assumption that x is an unspecified source, unknown to the observer, whereas only y_1 and y_2 are accessible to observation. (A possible physical meaning of the unspecified source x can be the state of the system at a time $t - dt$ immediately preceding the time t of observation.) If it were not so, we would have to consider a channel $(x;Y)$, where Y stands for y_1 and y_2 (Figure 3) in a different, more classical way, making use of double conditional probabilities. The analysis would proceed as follows:

$$T(x;Y) = H(Y) - H(Y/x). \tag{5}$$

$H(Y) = H(y_1) + H(y_2/y_1)$ is substituted into $H(Y/x)$, which gives

$$H(Y/x) = H(y_1/x) + H(y_2/y_1,x).$$

By substituting $H(Y)$ and $H(Y/x)$ in (5), we get

$$T(x;Y) = H(y_1) + H(y_2/y_1) - H(y_1/x) - H(y_2/y_1,x). \tag{6}$$

Writing Eq. (3) instead of (6) means that we assume $H(y_2/y_1,x) = 0$. This assumption is in fact a consequence of the unspecified character of x. In effect, it means that the uncertainty in y_2 is zero if y_1 and x are specified. In other words, from the point of view of the system itself, there is no uncertainty at all as to y_2 when y_1 and its source x are given. The uncertainty in y_2 is only relative to the observer, as a consequence of the fact that the observer does not have access to x. Since the creation of additional uncertainty in y_2 by decreasing the observed constraints of the system (i.e., those between y_1 and y_2) still allows the system to be in a functioning state (complexity from noise), this new state must be admissible from the point of view of the real internal constraints governing the unknown organization of the system, that is, those between x (the unspecified, unknown source) and Y (which is observed).

12.4.2 Noise and Meaning

Transmission from One Level to the Other. One further step can be taken by considering the transmission of information from one level to another within a hierarchically organized system in terms of the information's meaning, which we shall define, in a restrictive way, as the efficiency of transmission.

We have already seen how the use of the complexity-from-noise principle implies a change in the sign of the effects of noise according to whether one is looking at the transmission within a single level or from one level to another.

Again, so far as the meaning is concerned, we must now distinguish between the transmitted information as it is seen by the system itself and what can be grasped from this by the observer. For the system itself, the transmission of information from one level to another must imply the existence of all that is needed for a channel of communication to function, namely, the three levels of Weaver, including that of the meaning of the information.

The Operational Definition of Meaning. Before going further, let us realize how the meaning of information can be understood for a natural (non-man-made and nonhuman) system, on an objective basis different from our introspective feeling or linguistic experience. We propose to define the observed meaning of information as its observed consequence on the receiver. In other words, we suggest unifying Weaver's levels *B* and *C* (semantics and efficiency), although we know that in our linguistic experience no such unity exists.

A good example of this is given by the functioning of the genetic code and the meaning of genetic information. On the one hand pure Shannon theory for the transmission of information restricted to the *A* level can be applied to analyze the protein–synthesis machinery as a noisy channel between the DNA nucleotides sequences (written in a four-letter alphabet coded in words of three letters) and the protein amino acid sequences (written in a 20-letter alphabet) (Atlan 1968, 1972). In such an analysis, the question of the meaning of the genetic information is disregarded when the only problem is that of the accuracy of the DNA expression into the protein structure. However, at the output of the channel this meaning manifests itself through the enzymatic activity of the proteins, and more generally through their function in the cell metabolism. Thus it appears that the meaning of the genetic information is to be found in the cell functions that the genetic message stimulates or inhibits when it is transmitted in the (DNA or protein) channel. Meaning as a cell-function efficiency may be viewed at different levels, that of the cell itself, for example, or that of the organism.

At the level of the species, the meaning of the genetic information may have to do with the selective value of the given species within a given environment. A precise definition of the selective value of information carriers has been proposed by Eigen (1971), who has studied a process of self-organization of matter by means of replications and interactions of such carriers (biomacromolecules). Here again, when these carriers

are duplicated an optimum nonzero percentage of errors in the transmission of information is necessary for the process of increase in information content to take place. This percentage appears as one of the parameters by which the selective value is defined. The selective value of information carriers is a particular case of a meaning of information where the receiver for which the information is meaningful is the natural selection system. Thus the value of the information for this system (i.e., its meaning) is related to the existence of noise in the replication channels.

As imperfect as it is from a psychological, introspective point of view, this proposed operational definition may be applied to, and include, the human linguistic meaning as a particular case. Here, the observed systems are the human cognitive and acting systems. From this point of view, the meaning of the messages received by these systems will be defined as the correlated observed changes that they produce either on the internal state of the cognitive system or on the observed output (i.e., behavior) of the acting system, or both.

Meaning of Information Within a Hierarchical System. Now, we as observers cannot in fact know the meaning of information transmitted from one (lower) level to another (higher) more integrated one. However, this meaning is what makes the structure and function of the system itself at its higher level of integration. If we knew it we would be in a position to understand the hierarchical organization of the system in a specific and complete way and would not need this probabilistic nondeterministic approach. At the same time, the system itself at its higher level obviously "knows" the meaning of this information, since it receives and reacts to the information in an efficient way that is manifested in its mere existence as an organized functioning system. On the other hand, although we do not understand the organization on a deterministic basis, what appears to us outside as noise within the system appears to have beneficial effects on this organization insofar as the complexity-from-noise principle is applicable. As Piaget rightly noticed, the very fact that the system is able to utilize noise to improve its organization means that this noise is not noise for the system. For us, however, this noise cannot be anything else, since it appears to us to be made up of random perturbations with no logical articulations relative to the organization of the system as we can know it on a deterministic basis.

We are therefore led to suggest that what appears to the observer as an organizational noise acting in the channels connecting different hierarchical levels is, in fact, for the system itself the meaning of the information transmitted in these channels. It is because we are using a formalism (the Shannon theory) from which the concept of meaning is absent that its expression appears as paradoxical, as the information-from-noise principle. In other words, the positive effect of noise appears as the con-

sequence of the negation of a negation: What is destroyed by the noise is information, but since it is information whose meaning we do not know, its negation can be used indirectly to appreciate the effects of the positive, meaningful (to the system) information that is still unknown (to the observer).

Thus it is our opinion that the complexity-from-noise principle may have far-reaching consequence: the possibility of widening the scope of the Shannon information theory without losing the benefit of its well-established rigor. This is achieved by taking seriously the role of the observer and applying a Shannon-like analysis to a noisy channel toward the observer. For this purpose, attempts like that of Bourgeois's graphic representation (see Section 12.3.3) may be fruitful.

12.4.3 Artificial Systems, Natural Systems, and Observer Systems

We have already mentioned the distinctions to be made between man-made, well-known artificial systems and imperfectly known natural systems. With regard to the latter, the existence of the observer and his position outside the system have appeared to be critical—a fact taken into account in defining the concepts and quantities related to such a system.

For artificial systems, a choice is sometimes possible between deterministic and statistical methods: the position of an unacquainted external observer of the system may be adopted for operational reasons, because total knowledge, although accessible, is less convenient than a statistical approach on the basis of a partial knowledge, as if the system were natural. In the case of natural systems, though, there is no choice but to resort to statistical methods like those of thermodynamics and information theory.

However, distinction must also be made between observed natural systems and human natural systems, where the observer is inside the system as a part (of a social system) or as a whole [an individual as an "assimilating" system, with senses both of biological and of cognitive assimilation (Piaget 1974)]. When we apply the above analysis to human systems we take the position of someone who would observe them from outside. This is a very particular and somehow artificial point of view. From it we observe things as if we do not intend to know the meaning for ourselves of what we ourselves are living—either as organized individuals or as an element of the social system. However, this point of view is merely a consequence of the extension of the scientific method to the phenomena of our life, in the form of the postulate of objectivity. We can see how this postulate takes the shape of a prejudice that neglects an important, perhaps essential part of the information available to us. Here we reach

the limits of this method transposed to human systems analysis: Although we have a direct access to the information that the system receives from itself, including its meaning, we neglect it because it is in the realm of what we call subjective knowledge.

As an example, it is worth analyzing briefly attempts to apply these ideas on organization to understanding psychic organization (Atlan 1973a,b; Ganguilhem 1975; Serres 1976). The theory of self-organization has been used to analyze the roles of memory and self-organization processes in the constitution of the psyche by learning and, more generally, by what Piaget calls assimilation—in both its biological and psychological sense. Some interesting conclusions on the nature of biological and psychological time can be drawn (Atlan 1973 a,b).

In its most general form, the complexity-from-noise principle has helped to provide a cybernetic understanding to the seemingly paradoxical death pulsion of Freud (Ganguilhem 1975). In its application to the problem of meaning in hierarchical organization, this principle has helped to suggest how what appears as noise and nonsense to the observer of the conscious level is in fact meaningful messages from the unconscious level (Serres 1976). However, it is at this point in the psychoanalytic approach that our remark must find its place: in effect the observer of the conscious and unconscious levels together is at once psychoanalyst and patient. The patient is rightly called the subject (Lacan 1966), being in the grammatical position of the one who is talking, that is, sending messages from the whole psychic system, while seemingly under objective observation by the psychoanalyst. This is why a very special status with respect to its scientific character has been attributed to modern psychoanalysis. While it has always aimed to be differentiated as a science from magic and religion, one is forced to differentiate it from science as well because of the special status it accords its object, which is that of subject! The epistemologist M. Foucault (1966) called it and ethnology "antisciences" for this reason. The psychoanalyst J. Lacan tried to express the problem by resorting to a primordial status of linguistic rules in the creation of the psychic organization as a whole. His first example of how these rules can be the basis of a self-generated symbolic reality appears to us with hindsight as another application of the complexity-from-noise principle: A random series of plus and minus signs can give rise to a set of symbols with very specific rules when it is seen at a different level of integration where the units are made of groups of signs.

Moreover, in social systems, the observer is not only an element of the system but also a metasystem: The system is contained by the observer inasmuch as the observer views it from outside. We have seen above that the transmission of information from one level to another implies a transmission of meaning (i.e., of the codes) from one level to the other. It is

the lack of knowledge of these codes for the external observer that gives rise to the apparent paradox of the information-from-noise principle.

In the case of social systems, individuals are contained in the system and bear their own coded information to be transmitted to the higher, social level of organization and vice versa from the social system code to the individuals. However, all this holds only from the point of view of an objective information, that is, if we forget that they themselves are the observers. In fact their positions as observers transform their individual codes of meaning into something more general than the social code. The latter is contained in the former inasmuch as the observed is contained in the observation. This is a source of difficulty, together with a new wealth of organization, specific to the social systems. The individuals who make up the system use and process an information with a meaning that acts at the same time at two different extreme levels: the elementary level of the constitutive parts and the most general level of a metasystem containing the society (and even the universe!), namely, the observer-cognitive system.

The order-from-noise principle, in a vague qualitative form, has been applied to social systems as a principle of permanent reorganization after disorganization due to the tensions between the individuals and the society: the individuals are viewed as sources of random perturbations for the social organization.

However, the peculiarities of the social systems just mentioned make more subtle the analysis of the tensions between individuals and societies. These tensions, which can culminate in what is called a "crisis," may be understood as a bad transmission of the meaning of information within the system itself, between the individual and the society. That is to say, the individual and collective codes of significations are not the same any more.

Two mechanisms can be imagined by which such a crisis can be avoided without being solved, thus being transformed into a prolonged state of latent crisis. It is suggested that this state has been reached by the developed societies, which provide us with two (extreme) examples of these mechanisms. The first mechanism is to impose the meaning of the social code on the individual in such a way that the individuals' codes will be repressed, as it is done in all totalitarian societies. The second possible mechanism is the opposite: to project the meaning of the individual codes and impose it on the social reality. This latter is done in the so-called consumption societies, where everyone wants to think that the only goal of the social organization is the satisfaction of individual wishes. In fact, the social organization resists somehow, at least because of the contradictions between the individual needs and desires. However, the individual's situation of being at the same time contained and containing allows

him to make such a projection. Similarly, in the totalitarian society, this situation allows the social code to be more or less "introjected" in the form of an ideology, which "convinces" the individuals—willingly or unwillingly.

In both cases this peculiar situation allows one code to be more or less repressed by another and maintains the system in this state of avoided but nonsolved crisis. There is still bad communication between the code of the individuals and that of the social system. According to our development above, this amounts to a functioning opposite to the complexity from noise. That is to say, this state amounts to a decrease in complexity, possibly corresponding to an increase in redundancy. Interestingly enough, in both symmetrical extreme cases, we can notice an increase in redundancy in the form of a tendency to an uniformization of the individual wishes in what is called today the "masses." Usually this uniformization is related to that of the mass media as the overwhelming means for social "communications." However, might it be that the development of these media at the expense of other means of communication—possibly more meaningful from an internal, individual life point of view—was necessary to avoid the explosion of societies in crisis?

Appendix

The Formal Theory of (Self-)Organization in Living Systems

The possibility for noise to reduce the redundancy of a system is the basis for a theory of organization able to account for (1) the opposite intuitive features of organization, namely, redundancy and variety, (2) organization as both a state and a dynamic process, and (3) the possibility of self-organizing properties and the conditions for their appearance (Atlan 1968, 1972, 1974).

The various proposed definitions of organization found in the literature follow two major trends, which contradict one another (Dancoff and Quastler 1953; Linschitz 1953; von Foerster 1960; Rothstein 1962; von Neumann 1966; Ashby 1967; Theodoridis and Stark 1969, 1971; Eigen 1971; Mairlot and Dubois 1974). By organization is meant either constraint between parts (i.e., redundancy) or nonrepetitive order (i.e., variety and inhomogeneity, as in Shannon's information content). In fact, these two intuitions correspond to two extreme views, according to which a model for the best-organized system would be either a perfect crystal or an apparently random but functioning mass of elements. Interestingly enough, neither of these extreme views fits completely our intuitive notion of what organization is.

Compromise Between Complexity and Redundancy: The Library Metaphor

When we look at real natural organized systems we are dealing in fact with some intermediate situation, an example of which is provided by a cultural system

contained in a library. The culture exists as an intermediate situation between complete independence of the books from each other (no constraint) and mere repetition (maximum redundancy). The latter case would reduce the culture to the content of our one single book. The former would not be compatible with the existence of a culture either, since each of the books would be an isolated system. The cultural system is made of what is common to all the books in the form of quotations, references, allusions, deductions, inferences, and so on. All this means some degree of communication between the books, although not perfect (i.e., with some ambiguity), which prevents them from being mere repetition.

Thus optimum organization must be viewed as a compromise between maximum information content (i.e., maximum variety) and maximum redundancy (Atlan 1968, 1974).

In a review on the recent experimental findings about the DNA organization in the nucleus of living cells, W. Nagl observed that this definition "fits the organization of the cell nucleus surprisingly well. Its structure and function are based on both variety (unique units of genetic information) and repetitiveness (reiterated units that are noninformative in a genetic sense)."

Mathematical Expressions of the Organization

A simple way to express the organization of a system as a dynamic process is to look at it as a time course of change in its information content H. In addition, the function H is split into a maximum information content and a redundancy function according to the classical definition of the redundancy:

$$H = H_{\max}(1 - R).$$

In this equation H is a measure of the information content of a system with internal constraints between parts measured by the redundancy R. $H_{\max}$ is the maximum potential heterogeneity computed by not taking into account the constraints—that is, by assuming complete independence of the parts. Thus H, being an increasing function of $H_{\max}$ and a decreasing one of R, appears to be the required compromise between them. Differentiating H versus time (again with the assumption that time means accumulated effects of noise-producing factors), we get

$$\frac{dH}{dt} = (1 - R)\frac{d\,H_{\max}}{dt} + H_{\max}\left(-\frac{dR}{dt}\right). \tag{7}$$

(This assumption ignores the evolution in time determined by a sequence of instructions in a program imposed by the designer and builder of the system from the outside. In a programmed system, the organization is that of the program and its measure may be given by the computer time necessary to have it run, or by the number of steps in a Turing machine as mentioned above for the estimate of the complication of an artificial man-made known system.)

The two terms on the right-hand side of (7) can be identified with the two effects of noise previously described. The first term has the meaning of a destructive ambiguity that destroys $H_{\max}$ (i.e., the total information transmitted from the system to the observer, counted without taking into account the constraints). It is the classical disorganizing effect of noise. Because of decrease in the con-

straints, dR/dt is negative, and the second term has the meaning of an autonomy-producing ambiguity that, as explained above, produces a decrease in the redundancy of the system. In other words, as the accumulation of errors acts by decreasing both H_{max} and R, the first term is negative and the second positive.

Now, dR/dt and dH_{max} are themselves two different functions of time that express the kinetics of the effects of noise on the system. It has been proposed that these two functions, together with equation (7), express the overall organization of the system, both structural and functional.

A particular case, limited to a channel between two substructures $(y_1;y_2)$ of a system, and a nonspecified source x emitting to the observer, was treated in detail. The following equation was proposed (Atlan 1968), where the two different ambiguities act together on the information content $H(S)$ of the system:

$$H(S) = H(y_1) - H(x/y_1) + H(y_2/y_1). \tag{8}$$

Its time derivative can be expressed by means of the generalized Yockey's equation (Atlan 1968) and integrated. Under certain conditions H in equations in (7) and (8) can be increasing in time.

Self-Organization by Decrease in Redundancy

We proposed to call self-organization a process where the change in organization with increased efficiency is not directed by a program but occurs under the effects of random environmental factors. A condition for self-organization (i.e., increasing H in time, at least up to a certain time) amounts to a minimum initial redundancy to start with.

In effect, according to this view a self-organizing system is a system redundant enough and functioning in such a way that it can sustain a decrease in redundancy under the effects of error-producing factors, without ceasing to function. This decrease in redundancy leads to an increase in information content or variety, which allows for more possibilities in regulatory performances as shown by Ashby (1958). In other words, self-organization appears as a continuous disorganization constantly followed by reorganization with more complexity and less redundancy. Additional mechanisms can be imagined at various levels of organization by which a system can regain redundancy in order to be able to evolve again. There is little doubt that DNA redundancy (in the form of additional chromosomes or else) must have played a central role in the species-evolutionary processes. Our cognitive system is another example of self-organizing systems, and here the paradoxical sleep and dream have been proposed as such hypothetical mechanisms for regaining redundancy (Atlan 1973a,b).

References

Ashby, W. R. (1958), Requisite variety and its implications for the control of complex systems, *Cybernetica* I (No. 2), 83–89.

Ashby, W. R. (1962), Principles of the self-organizing system, in *Principles of Self-Organization* (H. von Foerster and G. W. Zopf, eds.), Pergamon, Oxford.

Ashby, W. R. (1967), The place of the brain in the natural world, *Curr. Mod. Biol.* 1, 95–104.

Atlan, H. (1968), Applications of information theory to the study of the stimulating effects of ionizing radiation, thermal energy and other environmental factors: Preliminary ideas for a theory of organization, *J. Theoret. Biol.* 21, 45–70.

Atlan, H. (1972), *L'Organisation Biologique et la Theorie de l'Information,* Hermann, Paris.

Atlan, H. (1973a), *Conscience et desirs dans des systemes autoorganisateurs, in L'Unité de l'Homme* (Morin and Piattelli-Palmerini, eds.), Le Seuil, Paris.

Atlan, H. (1973b), Le principe d'ordre a partir de bruit, l'apprentissage non dirigé et le reve, in *L'Unite de l'Homme* (Morin and Piattelli-Palmerini, eds.), Le Seuil, Paris.

Atlan, H. (1974), On a formal theory of organization, *J. Theoret. Biol.* 45, 295–304.

Atlan, H. (1975), Organisation en niveaux hierarchiques et information dans les systemes vivants: Reflexions sur de nouvelles approaches, in *l'Etude des Systemes,* CNSTA, Paris, pp. 218–238.

Bourgeois, M. (1977), personal communication

Dancoff, S. M., and Quastler, H. (1953), The information content and error rate of living things, in *Information Theory in Biology* (H. Quastler, ed.), Univ. of Illinois Press, Urbana.

Eigen, M. (1971), Self-organization of matter and the evolution of biological macromolecules, *Naturwissenschaften* 58, 465–523.

Foerster, H. von (1960), On self-organizing systems and their environments, in *Self-Organizing Systems* (M. C. Yovitz and S. Cameron, eds.), Pergamon, New York.

Foucault, M. (1966), *Les Mots et les Choses,* Gallimard, Paris.

Ganguilhem, M. (1975), Vie article in *Encyclopedia Universalis,* Paris.

Gatlin, L. L. (1966), The information content of DNA(I), *J. Theoret. Biol.* 10, 281–300.

Lacan, J. (1966), *Ecrits* (esp., "Seminaire sur la Lettre Volée"), Le Seuil, Paris.

Linschitz, H. (1953), The information content of a bacterial cell, in *Information Theory in Biology* (H. Quastler, ed.), Univ. of Illinois Press, Urbana.

Mairlot, F. E., and Dubois, D. M. (1974), Basic criteria in cybernetics: communication and organization: advances in cybernetics and systems research, *Proc. Europ. Mtg, Vienna,* Transcripta Books.

McGill, W. J. (1954), Multivariate Information Transmission, *Psychometrika* 19, 97–116.

Morin, E. (1977), *La Methode,* Le Seuil, Paris.

Morin, E. (1973), *Le Paradigme Perdu: la Nature Humaine,* Le Seuil, Paris.

Nagl, W. (1976), Nuclear organization, *Ann. Rev. Plant Physiol.* 27, 39–69.

Neumann, J. von (1966), *Theory of Self Reproducing Automata* (A. W. Burks, ed.), Univ. of Illinois Press, Urbana.

Piaget, J. (1974), *Adaptation Vitale et Psychologie de l'Intelligence,* Hermann, Paris.

Rothstein, J. (1962), Information and organization as the language of the operational viewpoint, *Philosophy of Science* 29 (No. 4), 406–411.

Serres, M. (1976), Le point de vue de la biophysique, in Critique, Paris, *La Psychoanalyse vue de dehors* (special issue), March, 265–277.

Theodoridis G. C., and Stark, L. (1969), Information as a quantitative criterion of biospheric evolution, *Nature* 224, 860–863.

Theodoridis G. C., and Stark, L. (1971), Central role of solar information flow in pre-genetic evolution, *J. Theoret. Biol.* 31, 377–388.

Weaver, W., and Shannon, C. E. (1949), *The Mathematical Theory of Communication*, Univ. of Illinois Press, Urbana.